Multi-Frequency Synthesis Imaging with Multi-Scale deconvolution

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Abstract

In aperture synthesis, measurements from multiple frequencies can be combined to increase spatial frequency coverage and sensitivity during image reconstruction. One current goal in radio interferometry is to utilize the broad-band capabilities of new receivers to produce a high dynamic-range continuum image with noise levels consistent with the broad-band sensitivity, along with an accurate representation of any spectral structure across the observing band. In this paper, I will describe the formulation of the problem with emphasis on the ambiguity between spatial and spectral structure in such measurements, and discuss some existing and new multi-frequency deconvolution algorithms.

1. Summary

One current goal in radio interferometry is to utilize the broad-band capabilities of new receivers to do multi-frequency synthesis (MFS) imaging, a process in which measurements from a wide range of frequencies can be combined to generate a single continuum image. The MFS measurement process increases spatial frequency coverage and sensitivity during image reconstruction, but also introduces an ambiguity between spatial and spectral structure which must be correctly accounted for during deconvolution. The source of the scale-spectrum ambiguity is as follows. Consider measurements made at two different receiver frequencies that do not overlap in spatial frequency. Let the amplitude and phase of the two measurements differ by a certain amount. Without extra information, it is impossible to tell if this difference arises because the source has structure on multiple spatial scales and therefore different values at different spatial frequencies, or because the spectrum of the source is not flat between the two receiver frequencies, or a combination of the two. Some constraints come from measurements where a single spatial frequency is sampled at multiple receiver frequencies, but this information can be incomplete and needs to be used appropriately during deconvolution.

The goal of any MFS deconvolution algorithm is to produce a high dynamic-range continuum image with noise levels consistent with the broad-band sensitivity, along with an accurate representation of any spectral structure across the observing band. A few multi-frequency synthesis algorithms exist, but they have assumptions that restrict their use to a some special cases. One method treats multi-frequency measurements purely as a means to increase spatial frequency coverage, and this approach works well only on sources with flat spectra across the observing band. When applied to sources with spectral structure, the image fidelity is compromised, and the dynamic range is limited to 1000:1. Another algorithm, the MF-Clean [1,2], models source spectra as a Taylor series, but does not account for the contribution of spatial structure while constructing Taylor terms from the visibilities. It works well for fields of well-separated point sources with power-law spectra, but generates spurious spectral structure when applied to extended emission, limiting the dynamic range to 10000:1. A third procedure involves imaging every frequency channel independantly and thus eliminating any spatial-spectral ambiguity, but this has limited imaging sensitivity and fidelity because of the fewer measurements being used while imaging each channel.

An algorithm that can work for sources with extended emission and spectral structure on multiple scales must guard against any spatial-spectral ambiguity while still utilizing the increased spatial frequency coverage provided by the multi-frequency measurements. One method that is being tested is to augment the single channel deconvolutions with a continuum deconvolution on the residuals. This method has the potential to approach broad-band sensitivity levels on images with compact and extended structure and arbitrary spectra. Another method is a combination of the point-source MF-Clean, with the MS-Clean [3], a multiscale deconvolution technique, by representing the source structure and spectrum as a set of multiscale Taylor terms. A third method is a generic approach where the source structure and spectrum are modeled as a parameterized collection of flux components, and a numerical optimization is performed directly in the Fourier domain to fit for source parameters. All three methods are being tested on (E)VLA data, real and simulated, with the goal of establishing a viable data reduction technique for broad-band EVLA observations.

2. References

1. R.J.Sault and M.H.Wieringa, “Multi-frequency synthesis techniques in radio interferometric imaging” *Astron. Astrophys. Suppl. Series,* 108, 1994, pp. 585-594.

2. J.E.Conway, T.J.Cornwell, P.N..Wilkinson, “Multi-frequency synthesis: a new technique in radio interferometric imaging”*Mon. Not. R.Astr. Soc*, 246, 1990, pp. 490-509.

3. T.J.Cornwell, M.Holdaway, "Multi-scale CLEAN deconvolution", *Astron. and Astrophysics*, in press